THE

AMERICAN NATURALIST.

Vol. xi.—*JULY*, *1877.*—*No. 7.*

NOTES ON THE AGE AND THE STRUCTURE OF THE SEVERAL MOUNTAIN AXES IN THE NEIGHBORHOOD OF CUMBERLAND GAP.

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THE dogma of De Beaumont as to the parallelism of mountain chains of the same age has not lost its effect on the minds of geologists. The exceeding ability and untiring persistency with which its fallacies were urged has made it necessary to do more than refute them. Every instance of distinct contradiction should be well attended to and brought to the attention of naturalists. Having been trained in the theory of De Beaumont, I confess to having held to some remnant of faith in his views until I began my studies on the Appalachian system of mountains. Having examined this system in a preliminary way, throughout its extension from Gaspé to Georgia, I am convinced that as far as we can base our conclusions on the structure of one mountain system, it would be nearer the truth to say that mountain systems are more likely to be the product of parallel upheavals occurring in successive geological periods than of single epochs of elevation.

Some years ago I called attention to the fact that the Cincinnati axis was an outlier of the Appalachian system, and that it was formed, in part at least, as far back as the calciform sand rock of the Upper Cambrian period; also that the syenite axis on which Richmond, Virginia, now stands was uplifted after the general elevation of the Alleghanies had taken place,[1] since the formation of the Richmond coal-basin, and therefore must be referred to a time subsequent to the Trias if not to the Lias. The Blue Ridge was certainly elevated, at least in part, before

[1] I have since found that the parallelism of the Cincinnati axis with the Appalachian system had been previously noticed by Prof. J. M. Safford, State Geologist of Tennessee.

the formation of the Appalachian coal-field, so that the east and west section, from the Mississippi River to the sea across the Appalachian mountain system, gives us evidence of four distinct periods of elevation, the separation of which is recognizable on even a cursory inspection. I was not prepared, however, to find the additional evidence of the succession of elevations which has been given me by the study of the region lying between the Unaka Mountains of North Carolina and Central Kentucky. The work of the Kentucky Geological Survey in connection with the Harvard Summer School of Geology ranged during the last two summers over this area. As the results of this exploration must wait, it may be, some years before publication, I shall summarize some of the most important points that bear on this question.

The geologist who is accustomed to the aspect of the Alleghanies in Pennsylvania will be struck with the change in the appearance of their continuation in East Tennessee. In place of the long-drawn symmetrical arches of the Pennsylvania section, we have here in East Tennessee a great irregular table-land crossed from north to south by narrow wall-like ridges, which have, in some cases, a length of over one hundred miles. A close study of the country shows that these ridges are in most cases the more or less retreated walls of fault lines, which have a singular directness in their course and uniformity in the depth of their throw.

The increase in the amount of faulting that took place in the formation of the Alleghany Mountains south of Pennsylvania becomes perceptible as we pass the Potomac River. In the mountainous regions of Virginia, along the waters of the south fork of that river, it begins to mark itself on the topography, and the change continually increases as we pass toward East Tennessee. Although still much in doubt as to the nature of the influences which have brought about this change, I venture to suggest the following explanation, which seems in a measure to satisfy the conditions of the problem.

On looking at the sections exposed in Southwestern Virginia and Eastern Tennessee, it will be seen that there are two classes of ridges found in this district: one formed by faults and the other by escarpments of the retreating crest of the anticlinals. It will be seen that the fault ridges have been formed on either side of the anticlinal ridges, though there is but one considerable ridge formed in this manner on the western side, while there

are three or more on the eastern side. After a good deal of consideration of these peculiar features, I have come to the conclusion that this change of the structure on the southward extension of the Alleghanies can best be accounted for by assuming the following conditions: First. That in place of the relatively narrow ridges of the Pennsylvania district, the uplifts which occurred here took the shape of one or more very broad anticlinals having a transverse width of sixty miles or more. Second. That each of these anticlinal axes was fractured by faults along several lines for its whole length, the result being to tumble the fissured strata over each other, leaving only the central part of the anticlinal still complete. Third. That the more massive the Blue Ridge to the eastward becomes, the more intense do we find this faulting action, on the east showing some relation between this faulting and the mass of the old mountains. I have long been of the opinion that the faulting in any mountain region becomes greater as the anticlinals widen or tend to take on some of the characters of the Alpine "massifs." It is not difficult to imagine a reason for this general occurrence of faults in broad folds of mountain masses; a small fold may have some sustaining power to its arch, and can await the gradual movement of strata to fill up its suddenly formed cavities. A broad fold will necessarily be weaker; the creeping of the strata into positions fitted to sustain the uplifted ridge may not be quick enough to keep furrows from forming, as they have formed in this Tennessee district.

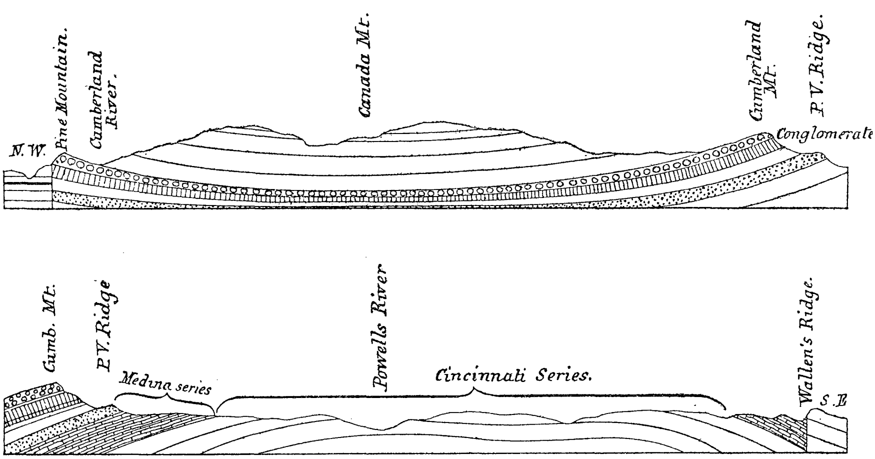
It is not so easy to perceive a reason for the greater width of the anticlinals in this part of the Appalachian chain. There are, however, good mechanical reasons why the width of the ridges and furrows which make up a mountain range should have a width proportionate to the depth of the strata involved in the movement. An illustrative experiment showing the principle that determines this is easily made by taking a number of sheets of heavy paper and compressing them from the sides. The more sheets we affect by the pressure, the broader the resulting folds will be.

In any region where successive mountain upheavals have taken place, as in the Alps, there is often evidence going to show that the lateral force operated at first to disturb the more superficial beds, and then in succession the deeper ones became affected. It is this, I believe, that gives us the Swiss *massife* plan of mountain-building. I conceive that in the Alpine region there was first a set of folds after the essential plan of the Jura Mount-

ains, then at a succeeding time there was an upheaval that affected a deeper set of beds and formed far wider folds, on which the earlier uplifts were upborne as the lesser waves of the sea upon the greater ridges. At the same time the broader folds were much faulted, so that the whole mass became exceedingly complicated in its structure. The Appalachian system, in its extremely varied yet comparatively simple conditions, presents us with a number of peculiar connections and separations of these two classes of folds. The Cincinnati axis, for instance, is a sample of the broad fold of the simplest character. This fold seems to have been lifted with extreme slowness, and has a height of only a few hundred feet, being certainly not over fifteen hundred feet in height at any part measured from the bottom of the synclinal to the top of the ridge. But notwithstanding the slow formation and moderate elevation of this fold it has been somewhat affected by faulting in a direction transverse to its axis; these faults are, however, relatively very small. It seems to me that the East Tennessee region has had its form given by an effort to produce very broad and long anticlinals somewhat on the Cincinnati model, but of far greater height. One of these ridges, the Cumberland anticlinal, if it had retained its form, would have had a length exceeding one hundred and fifty miles, a width of sixty miles, and a height exceeding twelve thousand feet. The parallel faults reduced its height to less than half this height, and left an indistinct central anticlinal and a set of parallel fault mountains, one on the west, and four or more on its eastern side. According to the theory of De Beaumont these several mountain ridges, the central anticlinal and its several parallel monoclinal or fault-mountains, should have been of the same age, the product of a single cataclysm. The evidence, however, has led myself and my assistants of the Summer School of Geology and the Kentucky Survey, who have studied this country, to a very different conclusion. We have been forced to the conviction that the central anticlinal is of relatively ancient age, dating back primarily to a time soon after the expiration of the carboniferous time, while the other monoclinal mountains have been more or less gradually formed, some having been uplifted at a geologically very recent date. This succession has been determined by the only means we have of fixing the age of neighboring parallel faults in a region of this description, namely, by comparing the rate of the escarpments formed by the several fractures. The central escarpments, as will be seen from the accompanying figure, there covering the

anticlinal, have gone back as much as six or eight miles from the top of the arch, while the lateral escarpment of Pine Mountain has not retreated more than half a mile from its original place. After making all due allowance for possible differences in erosion rate of the two forces, it will be impossible to believe that erosion has acted on these two faces for equal lengths of time. There can be no doubt left in the mind of any one who studies these escarpments and satisfies himself of their relation to the geology of the neighboring districts, that their outcrops were made at periods widely remote from each other.

If there should be any need of accumulating proofs on this point, they could be found in a number of other circumstances



(FIG 70.) DIAGRAMMATIC SECTION ACROSS THE CUMBERLAND SYN-ANTICLINAL.

connected with them. The Pine Mountain fault, for instance, is characterized by a wonderfully rectilinear front, being hardly swerved from a straight line in fifty miles of its length. Throughout this distance the fault that made the escarpment is hardly half a mile from the summit of the crest. The Cumberland Mountain, which is an anticlinal escarpment, is an exceedingly irregular line, often departing as much as a mile from a direct course, and cut through and through at many points by streams. These irregularities in the one case and the regularity in the other attest the difference in the age of the two escarpments. There is still other evidence, the nature of which, however, it is not easy to make plain in a few words. This evidence may be briefly stated as follows: The streams on the west which head against the Pine Mountain are generally characterized by a

singularly low rate of fall; in several cases they run for miles without the least contact with their bed rocks, in fact with many feet of alluvial strata between their beds and the rock in which their troughs are excavated. I have been unable to explain this peculiarity save on the supposition that the district through which these streams course has been somewhat lowered by the movements which formed the Pine Mountain fault. If this be really the case, then we are compelled to suppose that the later movements of this dislocation — if the dislocation has indeed been, as I am disposed to believe, the product of a series of movements, — must have taken place after the drainage of this country had been entirely established, when each crest ran on its present line. I am led to the opinion, all the evidence being taken into account, only a part of which I can discuss here, that the escarpment of the Pine Mountain fault is now retreating from the line of breakage at the rate of not less than one foot in one hundred years. The rocks comprising the abrupt declivity are of a generally perishable nature and wear out readily under the action of frost and rain. This rate of retreat would give an age of not over five hundred thousand to one million and a half of years as the time that has elapsed since the formation of this fault. I am quite well satisfied that this estimate for the antiquity of the Pine Mountain fault is far within the truth, that it is in fact the result of disturbances which came in the time of the later Tertiaries.

I hope to elaborate these observations on the conditions of the Alleghany system in the Memoirs of the Kentucky Geological Survey; at present it is only possible to set forth the evidence in the briefest manner, with the special aim of calling the attention of students of physical geology to the evidences of recent action in the mountain-building forces in this part of the Appalachian district. I am confident that, more than any other mountain action known to me, they tend to show that the strains which are relieved by mountain folds and faults are, in certain cases at least, continuous actions leading from time to time to movements that afford relief thereto. No one can study the structure of the section between the eastern face of the North Carolina mountains and the western side of the Cincinnati axis without being driven to the hypothesis that in a geological sense the mountains contained therein have been in a process of continuous formation since the beginning of the lowermost Cambrian deposits. Perhaps less distinctly shown, but it seems to me quite clear, is the evidence

that the relief of these mountain-building barriers has been found in two ways: First, by the folding of the earth into ridges and valleys, or synclinals and anticlinals; second, by the forming of faults which are the product of the rupturing of the folds, and must be regarded as resulting from the failure of the lower lying rocks to follow and support the more superficial beds in their upheaval. This failure may have been in part caused by the exceeding width of the upthrown ridge, which could not maintain itself until the deeper beds could adjust themselves to support it.

When we consider the numerous cases in this district where the drainage crosses faults of many thousand feet of throw, we are driven to the belief that whole geological periods have been required for the movements involved in their formation. I am inclined to believe, however, that while the greater part of these dislocations have been made slowly, some of them have been formed with a great suddenness, and attended by movements of extreme violence. Besides the faults traversed by streams whose courses have not been turned or interrupted by these gigantic dislocations there are others which exhibit unequivocal evidence of violent movement in their formation. These evidences are various in their nature, but they are most conspicuous in the shattering of the walls on either side of the fault. The best instance of this sort of disturbance is found about the fault which passes through Cumberland Gap, and by the weakness it has given to the rocks has brought about the formation of this mountain pass. This remarkable fault is marked by the presence of a belt of rock fifty feet or more in width, which has been fractured into a breccia by the violence of the movements which have attended its formation. The breccia is cemented by an infiltration of iron derived from the adjacent carboniferous series of rocks. A careful study of this breccia has convinced me that the fault is the product of many successive movements, though each of them must have been attended by a certain beating of the walls against each other. This fault, it should be noticed, is transverse to the direction of the great faults in this system of mountains, and is limited to the Cumberland synclinal, extending from a little beyond Cumberland Gap on the east to the gap in the Pine Mountain at Pineville. It differs also from the great parallel northeast and southwest faults which we find at Clinch Mountain, Mound Hill, and other points, in the irregularity of its throw, which differs not only in amount but in direction in a curiously irregular way. I believe that it owes its formation to the com-

pression strains which take place in the synclinal fold of the Cumberland. It is readily to be perceived that the nature of the strains developed by the synclinal folds must vary greatly from those which are formed beneath the anticlinals of a mountain district.

I only propose to call attention to the great problems in structural geology which this region presents to us, with a view of interesting our students of dynamic geology in their solution. More extended discussions of these questions will be given in the forthcoming volumes of the Memoirs of the Kentucky Geological Survey.

THE STUDY OF ZOÖLOGY IN GERMANY.

BY CHARLES SEDGWICK MINOT.

II. THE METHODS USED IN HISTOLOGY AND EMBRYOLOGY.

THE use of the microscope goes hand in hand with the work of zoölogists in Germany, and it is there that we find the greatest number of means employed to render the objects suitable for examination. I have frequently heard American zoölogists express a slight distrust of histological methods, — well founded, perhaps ; it ought not to lead to the rejection of the benefits to be obtained from using them, but merely to greater caution in employing them.

It is well known that animal tissues and organs consist of cells of various kinds, variously grouped together. The forms which these cells can assume lead to the most curious transformations, so that things as different from one another as muscular fibres, blood corpuscles, and ganglion cells can be traced as modifications of the same primitive form. The work of microscopic anatomists is to detect the changes which the simple cells of embryos undergo in the course of their transformations into the components of the tissues of the adult, and to investigate in detail the final results of these metamorphoses. It is much to be desired that America should assist more in this work, and it is with the hope of stimulating some persons to do so that this article is written.

In the tissues of the adult we find the cells arranged in a definite manner, and we have consequently to examine the shape and character of the single cells, and then their relation to one another. Simply placing a small piece of an organ underneath